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Technical Letter
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Engineering and Design
PRACTICAL ASPECTS OF APPLYING GEOSTATISTICS
AT HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE SITES

1. Purpose. The principal purpose of this ETL is to introduce the reader to geostatistical techniques and to demonstrate their basic utility with respect to HTRW site investigations. The ETL also will include a discussion of statistical concepts that support the science of geostatistics. Practical aspects of geostatistical techniques will be discussed in two ways. First, practical references will be made, when appropriate, during the discussion of statistical concepts, and second, examples describing several aspects of the use of geostatistical techniques in HTRW site investigations will be presented and discussed in a section of this ETL specifically dedicated to providing working examples. This ETL also will include a brief literature and software review; review of geostatistical applications; comparison of information that is generated with geostatistical methods to that information obtained using classical statistical methods; and some more recent geostatistical methods, such as conditional simulation.

2. Applicability. This letter applies to all USACE commands having HTRW investigation, design, and remedial action responsibility within the military or civil works programs.

3. References. Documents referenced in this ETL are listed. Appendix A contains additional references useful in geostatistical application.

a. EM 200-1-2, Technical Project Planning Guidance for HTRW Data Quality Design.

b. ASTM D-5922, Standard Guide for Analysis of Spatial Variation in Geostatistical Site Investigations.

c. ASTM D-5549, Standard Guide for Content of Geostatistical Site Investigations.

4. Distribution Statement. Approved for public release, distribution is unlimited.

5. Discussion.

a. Geostatistics is a powerful tool to assess relationships among data obtained from various locations. It allows optimization of sample spacing and frequency. More importantly, geostatistics also allows one to effectively estimate parameter values in areas between actual sample points and quantify the uncertainty of the estimated values. This can be very valuable in risk management and design decision making. This ETL builds upon the principles introduced in EM 200-1-2.

b. The ETL contains examples which illustrate the statistical principles discussed throughout the document. Not every application of geostatistics to HTW projects could be illustrated, however, and the user must be aware of the basic principles and seek appropriate applications. Specific examples of typical cost-effective applications of geostatistics are also given here.

(1) Geostatistics, by the construction of a variogram based on preliminary sampling, can be used to determine the **typical separation of sampling points that delineate uncorrelated data**. The range of the variogram is used as a basis for selecting a sample spacing that minimizes costs and provides independent data for determining, for example, average exposure values for risk assessment. First, an adequate number of preliminary samples are analyzed from the site (refer to section 4-3). Second, a variogram is constructed using techniques described in Chapter 4. Third, the range of the variogram, as defined in section 2-3 is determined. Lastly, the range or some multiple or fraction of it, is chosen for future sample spacing. The variogram should be updated as new data are collected. For example, the variogram may indicate data spaced more than 200 ft apart are uncorrelated. Closure sampling may then be proposed to be spaced every 200 ft or more along an excavation. Smaller spacing results in unnecessary duplication of information and unneeded expenditure of funds.

(2) Geostatistics, through block kriging, can yield **estimates of the average concentrations to be encountered** in a typical daily excavation area/volume. For applications such as excavation of near surface contamination, two-dimensional block kriging could be used to estimate mean contaminant concentration for specific excavation areas. Although this document does not address three-dimensional block kriging for estimating mean concentrations within given volumes, additional guidance and tools for three-dimensional kriging are available through references cited in Appendix A. Alternatively, one can use two-dimensional block kriging to estimate mean concentrations in different layers within a given volume. These estimates can then be averaged to approximate the overall average concentration within the entire volume. This assumes adequate data exist to perform the two-dimensional block kriging at the different depths. To perform two-dimensional block kriging, adequate site characterization data are collected (refer to section 4-4). Second, the data gathered from the areas of interest are used to construct a variogram, as described Chapter 4. Third, the variogram is

modeled as described in section 4-6. Lastly, the model is used to perform block kriging, as described in section 2-4 for blocks of a size comparable to the daily excavation area/volume. The block-kriged values can then be used for estimating the treatment plant loading, etc., related to that block. The kriging also quantifies the possible variance in the average concentration for each block that can be used to manage the risk of operating a treatment plant.

(3) Exposure concentrations for risk assessment purposes can be computed, using geostatistics, even though the site characterization data are somewhat clustered or were collected using biased sampling strategies. Assuming the data are already available and adequate in number (refer to section 4-4), the first step is to compute a sample variogram, as described in Chapter 4. Second, the variogram is modeled as described in section 4-6. Next, this model is used in performing a block kriging operation over the inferred exposure area, as described in section 2-3. Finally, the block kriging value can be used, along with the kriging variance, **to determine the exposure point concentration**, assuming the data were normally distributed (or were transformed to be normally distributed).

(4) The last example describes the use of geostatistics **to quantify project risk for excavation or treatment volumes**. Even with ample site characterization point data (borings or wells), the limits of the treatment zone are imperfectly defined. Geostatistics allows one to evaluate the risk that the size, and therefore cost, of the remediation may be larger or smaller than expected. First, site characterization is performed and adequate data are collected (as described in section 4-4). Second, the data are transformed by assigning a value of one or zero, depending on whether the value is above or below, respectively, a given clean-up value or other criteria. Third, the transformed data are then used to construct a variogram as described in Chapter 4. Fourth, this variogram is modeled as described in section 4-6. Next, this model is used in performing indicator kriging as described in section 2-6. The kriging estimates essentially reflect a

probability that the concentration at the points of estimation exceed the clean-up value or other standard. These kriging estimates can be contoured to define areas or volumes of material that have a certain likelihood of exceeding some cleanup value. The contour value is essentially the probability of exceedance. Lastly, the size of the area defined by different probabilities of exceedance can be determined and, using a unit cost or similar approach, a cost-versus-risk curve can be developed. This can be used in programming money for the project, as a basis for negotiating cleanup levels with regulators, or to help determine if the cost and time of additional characterization work will be offset by less risk during construction. Alternatively, rather than transforming the data to ones and zeros, the actual values are kriged and the kriging variances can be used to determine prediction intervals on each estimated value as described in section 2-6. In the vicinity of the point estimate, these prediction intervals can be used to define the spread of potential values expected within a given probability. This assumes the data are normally distributed or have been transformed to be normally distributed.

6. Actions Required.

a. USACE elements identified in paragraph 2 shall consider applications of geostatistics as


FOR THE COMMANDER:

2 Appendices
App A - References
App B - Notation

described in this document as appropriate. This is particularly true during planning of large-scale site characterization efforts or when there are risk management or design decisions to be made that must consider the uncertainty of site characterization results. The same USACE elements should also encourage the use of geostatistics, where appropriate, by their contractors.

b. USACE elements shall make every effort to familiarize staff members actively supporting HTRW projects with the fundamentals and potential benefits of the application of geostatistics. This letter is a good starting point for learning about the use of geostatistics for HTRW projects. Users are encouraged to attend appropriate training.

c. This letter sets out procedures for the technically correct application of geostatistics which are consistent with current practice, such as set forth in ASTM D-5922 and D-5549. The technical procedures outlined herein shall be considered when performing USACE in-house geostatistical analysis or reviewing such analyses done by USACE contractors.


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